Suppressor Engineering 101

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Intent:

The intent of these posts is to give a potential designer of a suppressor some idea what is involved in the proper design of a suppressor. These posts will not and cannot cover every possible design configuration that are possible but will give basic guidelines on the most typical methods of construction currently used in the suppressor industry. I will answer general design questions within some limits but I will not answer specific questions on a design unless you pay me for my work. I am employed as an engineer for a living and therefore if you want use of my knowledge you will need to hire me. I will also not address baffle design from the standpoint of gas flow but only from a structural standpoint. It is up to the designer to create the desired gas flow characteristics to maximize the suppression effect.

Definitions:

Here are some of the terms I will be using and their definitions.

Tensile Stress = Tensile stress (also referred to as normal stress or tension) is the stress state leading to expansion; that is, the tensile stress may be increased until the reach of tensile strength, namely the limit state of stress.
Compressive Stress = A stress that causes an elastic body to deform (shorten) in the direction of the applied load.
Hoop Stress = Circumferential stress in a cylindrically shaped part as a result of internal or external pressure.
Safety Factor or Factor of Safety = the ratio of the breaking stress of a structure to the estimated maximum stress in ordinary use.
Buckling = Failure mode characterized by a sudden failure of a structural member subjected to high compressive stresses.
Joint Efficiency (JE) = The ratio of the strength of a joint to the strength of the base metal, expressed in percent.
ASME = American Society of Mechanical Engineering.

Defining the Design Parameters:

Before you begin your design you must define all the parameters that you can. This will narrow the number of design options that can be made and dictate some other options.

You will need to define the following items:

Caliber & Cartridge: Self explanatory, what caliber/cartridge are you going to design the suppressor for.

Design Temperature: This can vary greatly depending on the caliber/cartridge, barrel length, and rate of fire.

Tube Diameter: Self explanatory, though once you begin the design you may decide to change the diameter initially specified.

Mount Design: Self explanatory, this will be up to the designer to determine how the suppressor will be mount on the firearm.

Bore: The diameter of the bore for the suppressor, size of hole through the baffles will need to be determined. The bore on some designs can be tapered to increase in size as the baffles get farther from the muzzle of the firearm. Typically, bore diameter is a constant in most suppressor designs. How do you determine what bore you should use? There are several factors that affect the selection of the bore diameter. The closer the bore diameter is to the outside diameter of the projectile the typically quieter the suppressor will be. The problem with very tight bores is the chance of baffle strike increase. The run out of the suppressor will also effects the required bore diameter. As a suppressor length gets longer, the run out will also increase and should be allowed for in the design. The mounting system affects the run out since all mounting systems have tolerances. The bore therefore should be selected with these factors in mind.

Suppressor Shell Type: If you are going to use tubing as the material for the suppressor shell then you need to select the type. Depending on the material you are using, tubing can be manufactured many different ways. The essential difference between them is if there is a longitudinal seam in the tubing. Seamless obviously is made without a seam where as seamed tubing is welded using various methods. Seamless tubing has a joint efficiency of 1.0 or 100%. Welded tubing can vary depending on the type of weld and the inspection level. EFW (Electric Fusion Welded) or ERW (Electric Resistance Welded) are two methods that are commonly used to make seamed tubing. The joint efficiency can be as low as 0.70 or 70% and as high as 100% depending on inspection levels. Lower the JE the thicker the tubing will be needed to hold the pressure. When ordering the tubing you need to know what the inspection level is if you want to have the best JE. Typical inspection would be full radiography of the weld seam for defects. Remember all tubing has as far as wall thickness, ID and OD. Tolerances can be as high as 12.5% of the dimensions. When doing any calculations for pressure retaining capability of the tubing, the wall thickness tolerance needs to be deducted. DOM (drawn over mandrill) tubing will have the tightest tolerance for the ID and is usually specified in construction of suppressors. Remember not all DOM tubing is seamless. Calculations to determine the hoop stress of tubing under internal and external pressure can be found under the ASME Sec. VIII Division 1 or 2 Boiler Pressure Vessel Code. The BPVC has equations for thin walled pressure vessels of various shapes as well as suggested JE for different types of welds.

Safety Factor: The safety factor that you decide on will be used in the calculations of the various components. ASME suggests a safety factor of 3 to 4 for pressure vessel in various services. Obviously the BPVC was not written for designing suppressors but it at least gives some equations that a lay man can use to determine some thicknesses required for pressures. The BPVC is very complex so it would behoove the designer to hire expert help or become familiar enough with the BPVC that they feel confident in its use.

Determine Pressure in First Chamber:

The first chamber consists of volume between the rear cap and the blast baffle. The suppressor designer needs to determine what the pressure is in this are so that they can design the tubing and junctions accordingly. Using an internal ballistics program you can get the pressure at the muzzle of the firearm just before the bullet exits. You should select the shortest barrel you ever expect to mount the suppressor on and use that in the internal ballistics program so it will yield the highest pressure expected. A good designer at this point will use a safety factor increasing the pressure. Determining the pressure in the first chamber is rather difficult and not exact. The only method to estimate this pressure available to the lay man is using the idea gas law even though the gasses are far from acting as such. Calculate the volume of the barrel bore including the chamber. The ideal gas law basically states in our case that the pressure1 X volume in the bore area is equal to pressure2 X volume of the bore + the first chamber. All you need to do is solve for the pressure2 to find what to approximate the first chamber pressure at for the design. Saying this is a gross exaggeration of what is going on is an understatement calculating the reality is extremely complex. It is obviously best to be real conservative with your numbers and add safety factors in everything you do.

Determine Minimum Tubing Thickness for Pressure Only:

Using the equations for a thin walled cylinder under internal pressure found in ASME VIII Section 1, you can determine the thickness of the tubing required to retain the pressure found in the first chamber. You will have to use the JE of the tubing you selected, the safety factor and the appropriate allowable stress. $t=Pr/(SE1 - 0.6P)$ t=thickness, r=radius ID, P=pressure, S=selected allowable stress for the material used, E=joint efficiency. Once you determine t, you need to add the mill tolerance to it to get you minimum required for pressure. Remember this is for pressure only and does not take any structural loads into account that will be addressed later.

Construction Method:

The amateur suppressor maker may have restrictions of the type of construction they can do. Two typical outer tube construction types are welded and threaded. Threaded design has the advantage of not requiring advanced welding skills and using materials that do not lend themselves to welded construction.

Threaded End Caps:

The end caps on a threaded design are retained with threads. There are two types of mating of the end caps to the suppressor tube. The baffle stack can be such that the stack has the threads that retain the end caps and will place the outer tube in compression. The other method, and most common thread the outer tube and the OD of the end caps. The tension baffle stack usually requires some sort of seal since high pressure gas will vent around the end caps. Typically an O-ring is used for this seal but the main draw back with this design is temperature limits of the O-ring. Typically high temperature O-rings are restricted to 400 deg. F. In sub gun and pistol suppressors the design temperature is low enough that this is not a problem. Center fire rifle suppressor often exceed 400 deg F with very little shooting. Both methods suffer from unrestrained tubing ends. This means that the end of the tube is not restrained from expanding under pressure. The expansion in the radial direction of the tube causes problems with sealing and threaded end caps that need to be addressed in the design.

Threaded Tube/End Cap Design:

When evaluating the loads in this type of design to determine the thickness required for the tubing, you need to take into account the thread depth, number, tubing thickness, and engagement interface areas. As the shot is fired the tube will expand due to the internal pressure. This pressure will also have reaction forces that will try to press the end caps axially from the tube. The threads are there to retain these end caps. Since the rear cap is mounted to the barrel, the suppressor tube would be under axial pressure forces trying to separate from the rear cap.

Some assume you have calculated the tube required thickness for pressure as above to be t. Now you need to determine how much deflection the tube will have at the rear cap end due to pressure. There are two common methods for doing this, Roark's Formulas for Stress and Strain or Finite Element Analysis (FEA). The reason the deflection is important, is as the tube deflects outward under pressure the threads will disengage and there will be less thread bearing areas. Threads that were satisfactory without tube deflection can suddenly fail to me the requirements for maintaining the rear cap. Once you have the tube deflection you can size the threads for the rear cap.

The threads for the rear cap should have sufficient shear area to withstand teh pressure end load on the rear cap. So if you have a Tube ID of (d) and a first chamber pressure of (P) you can calculate the end load on the rear cap. End Load L=((Pie*d^2)/4)*P all dimensions are in inches and pressure is in psi. End load of the rear and front cap can have a force component contributed by differential thermal expansion of the baffle stack if it is designed as a compression stack. To determine the load from compressive loads due to the temperature differential, you must first assume what the temperature differential is. Using the your final design temperature, subtract the assumed differential from the design temperature. You now have the design temperature of the inside core and the outside tube for non steady state conditions. Given an assumed overall length, material coefficient of thermal expansion and the two temperatures you can calculate the length growth of the outside tube and the baffle stack. If they are the same material then the stack will grow more than the outside tube. This difference in length results in end loads on the caps. All of this can be found on the web.

Now that you have your pressure end load you add it to any end load contributed by the differential thermal expansion. This total load is what you use to size the depth of the threads and engagement length. Obviously, adding safety factors in your numbers is a good idea since there can be unforeseen loads as well as defects in the interface.

Sizing the threads, pitch diameter and shear area are of great concern to you. The deflection of the tube must be taken into account when you are looking at the thread depth. You do not want the threads to become disengaged from each other. Using the sear area of one thread turn, the allowable stress of the material and the factor of safety you established it is easy to determine the number of threads required to retain the end cap. A Machinery Handbook is critical for determining the thread dimension. You also must check to make sure the depth of you thread cut subtracted from the tube thickness is not less than that required for pressure. Simplicity will show that you make the thread engagement the same for both end caps since the rear cap experiences the worse loads. Optimization of the design will result in less engagement requirement for the front end cap and a lighter can.

Welded Tube/End Caps

Though not radically different than the tube design for threaded caps, they do result in a thinner tube for the same loads. Since the end caps are welded to the tube the tube does not have the same free end expansion that can lead to thread disengagement and leaks. The welding takes care of the sealing requirements. The welds still need to be sized for the end loads determined via the same method as given for threaded end caps. You need to look at the end of the tube thickness to make sure that shear will not control the tube design. Shear is simply calculated by taking the cross sectional area of the tube cut perpendicularly to the bore axis and dividing it into the end thrust load in pounds. Compare this number with the tensile allowable stress selected for the material.

End Cap Design

After sizing the end cap and tube threads you need to determine the thickness required for the end cap it's self. Once again I have to refer to using Roark's Formulas for Stress and Strain or FEA analysis. End caps usually do not end up being a simple affair so the FEA is usually the best route though the hand calculations using Roark's can be used to determine thickness for pressure and end loading.

Baffle stack Design

There are essentially three types of baffle stacks I will address, monolithic, welded and non welded spacers and baffles.

Monolithic/Welded

Monolithic and welded can be treated much the same. These types of baffle stacks have the advantage, if designed correctly, of being loaded in tension.